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OIL DEBRIS DETECTION SYSTEM (ODDS)

Wayne A. Hudgins

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Final Report

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A flight test evaluation was conducted to investigate condition monitoring/diagnostic techniques. Using the UH-1 aircraft as a test bed, a diagnostic oil monitoring system was designed, incorporating high-efficiency, 3-micron filters and full-flow burn-off chip detectors in the engine and transmission, with burn-off detectors in the 42- and 90-degree gearboxes. A test program was structured to establish the feasibility and utility of the improved ODDS for use in the Army helicopter engines, transmissions and gearboxes. The results of the program have shown that the ODDS is a highly effective diagnostic system for monitoring the condition of gears and bearings in all Army helicopters. It has demonstrated reliable detection of failures while eliminating no-fault removals.

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SUMMARY

A flight test evaluation was conducted which involved a fleet of 50 UH-1 helicopters at the US Army Aviation Development Test Activity (USAADTA), Fort Rucker, Alabama. Of these, 38 were equipped with the Oil Debris Detection System (ODDS), incorporating ultrafine oil filters. The remaining 12 unmodified aircraft were used as a control fleet in order to monitor the oil condition in the absence of regular oil changes. Approximately 80,000 flight test hours were accomplished. The objectives of the evaluation were to attain 30 percent reduction in unscheduled removals brought about by poor diagnostics; to reduce the rate of false indications in current chip detectors; and to extend the oil change intervals from 100 to 1000 hours on the engine and from 300 to 1000 hours on the transmission.

The ODDS was designed and tested on the UH-1 aircraft; however, the results of this program have shown that it is a highly effective diagnostic system for monitoring the condition of gears and bearings in all Army helicopters. It has demonstrated reliable detection of failures while eliminating no-fault removals.

The ODDS requires no scheduled activity on the part of maintenance or operator personnel; it is passive until a symptom of impending component failure is manifested, at which time a chip light is illuminated. Due to its operating principle of fuzz discrimination, about 50 percent of the chip-light-caused precautionary landings/mission aborts are eliminated. Maintenance and operator personnel workloads are reduced significantly, with an overall increase in safety of operation.

The 3-micron filtration used in the ODDS is extremely beneficial in producing a "long-life" environment for gears and bearings. Components subjected to 3-micron filtration for many operating hours have proven to be far less distressed than similar components in standard filtered systems. Of particular interest is the great beneficial effect of 3-micron filtration on the wear rate of seals—the test fleet experienced a significantly reduced seal removal rate.

The results have also shown that the oil change intervals currently used are much too short and oil use can safely be extended to 2000 hours, which for all practical purposes puts the oil change on an on-condition basis. Filtration level has no effect on oil life.

Projected benefits expected from the ODDS are improvements in safety, mission reliability, and availability; an increase in engine, transmission, and gearbox mean time between oil change intervals; and an increase in bearing, seal, and gear life. These benefits combine to produce a substantial cost benefit, with payback calculated at less than 2 years on the UH-1 fleet as well as other aircraft.

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INTRODUCTION

BACKGROUND

For a number of years, the Applied Technology Laboratory (ATL) has conducted investigations into condition monitoring/diagnostic techniques. Among those techniques appearing to have greater potential for Army aviation were the oil debris monitoring systems. With the belief that interrogation of oil-borne information was the simplest, most practical way of diagnosing the condition of oil-wetted components, the oil monitoring program concentrated on methods of debris detection.

In the early years of the project, a large variety of schemes of debris detection were investigated and discarded for various reasons. Those schemes which were adopted and are currently being used by Army aviation are the Army Oil Analysis Program (AOAP) and the splash-type chip detectors. However, through the years these techniques have not been sufficiently effective; problems have continued to plague aircraft personnel, thus increasing interest in the improvement of diagnostic techniques.

It was concluded in the mid-70s that an effective full-flow chip detector would be the most accurate and practical means of diagnosis; thus the Oil Debris Detection System (ODDS) program was initiated. This report documents the design and flight test of the ODDS on the UH-1 aircraft.

PROBLEMS

Problems that have existed with the AOAP and the splash-type chip detectors which have stimulated the continued research efforts in the improvement of diagnostic techniques include the following:

1. The UH-1 helicopter experiences a chip light indication every 130 flight hours, with 86 percent of these indications being false or not related to actual failures in process. The resulting mission aborts and precautionary landings have obvious safety and economic impacts. The current AOAP, in addition to being a maintenance/administrative burden, is not effective in detecting debris related to gear and bearing failures.

2. The ineffectiveness of the diagnostic schemes has produced 20 to 40 percent no-defect replacement rates on engines, transmissions, and gearboxes.

3. Army helicopter oil change intervals have been approximately 10 percent of those of other Services. Oil changes have been made on Army aircraft engines and transmissions at a much too frequent rate, with the oil removed being essentially new.

4. Filtration levels used in Army helicopters have generally been in the 25- to 60-micron range.

OBJECTIVES

The objectives of this program were to attain 30 percent reduction in unscheduled removals brought about by poor diagnostics; to reduce the rate of false indications in current chip detectors; and to extend the oil change intervals from 100 to 1000 hours on the engine and from 300 to 1000 hours on the transmission.

CONCEPT DESCRIPTION - STANDARD/ODDS

STANDARD

The characteristics of the standard oil monitoring systems include splash-type chip detectors; a 25-micron filter in the transmission; a 60-micron filter on the engine; and condition monitoring capability through AOAP, chip detectors, and screen/filter inspections. The power train of the UH-1 aircraft includes four components with oil systems: engine, transmission, 42-degree gearbox, and 90-degree gearbox.

Chip Detectors

Splash-type chip detectors are used on the majority of the Army helicopters. The installation shown in Figure 1 is typical for a transmission. For engines, the splash-type chip detectors are usually installed in the accessory and/or reduction gearbox. The common characteristic of splash-type chip detectors is that they are located in sumps and their effectiveness depends on the low probability that the oil will transport representative debris to them; failure detection through splash-type chip detectors is therefore frequently unreliable. The design and location of the magnetic chip plugs in the standard UH-1 system allows particles to escape or be trapped prior to coming in contact with the detector plugs, and results in a very poor capture efficiency.

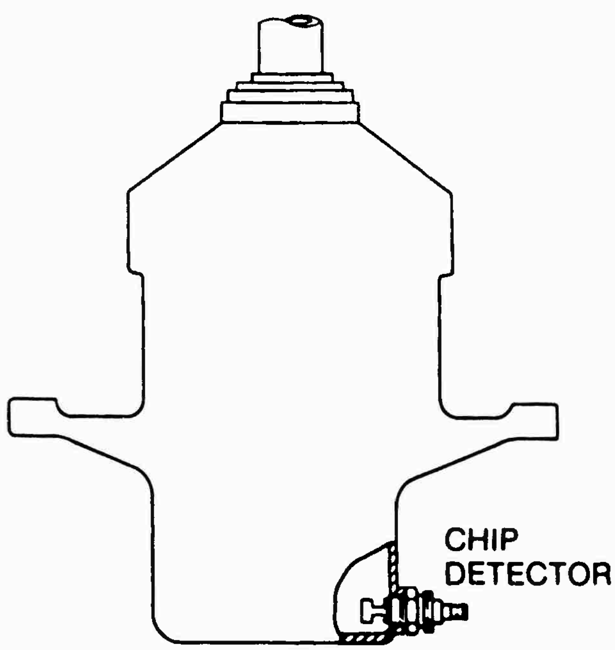

Figure 1. Splash-type chip detector.

Transmission Chip Detector. The standard UH-1 transmission chip detector is installed in the sidewall of the sump approximately 1/2 inch above the floor (Figure 2). The scavenge pump takes oil out of the sump and pumps it into a filter cavity which is located inside the transmission housing.

Engine Chip Detector. The splash-type detector in the T-53 engine is located in the accessory gearbox, as shown in Figure 3.

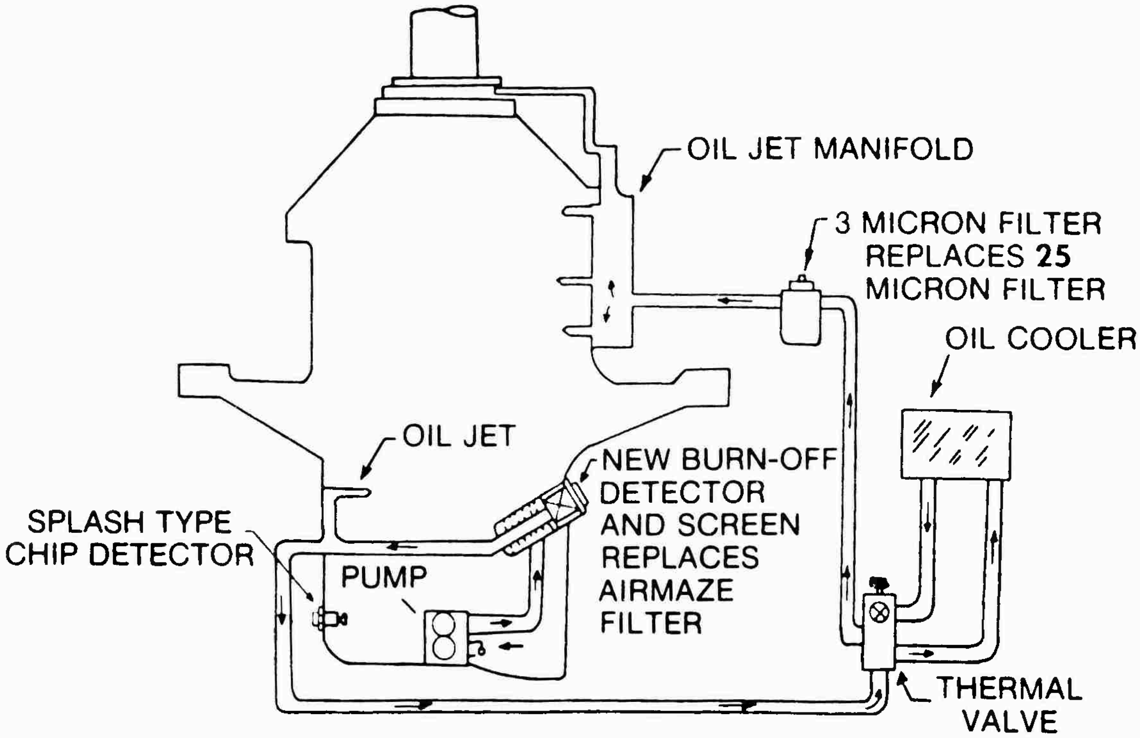

Figure 2. Transmission oil system schematic.

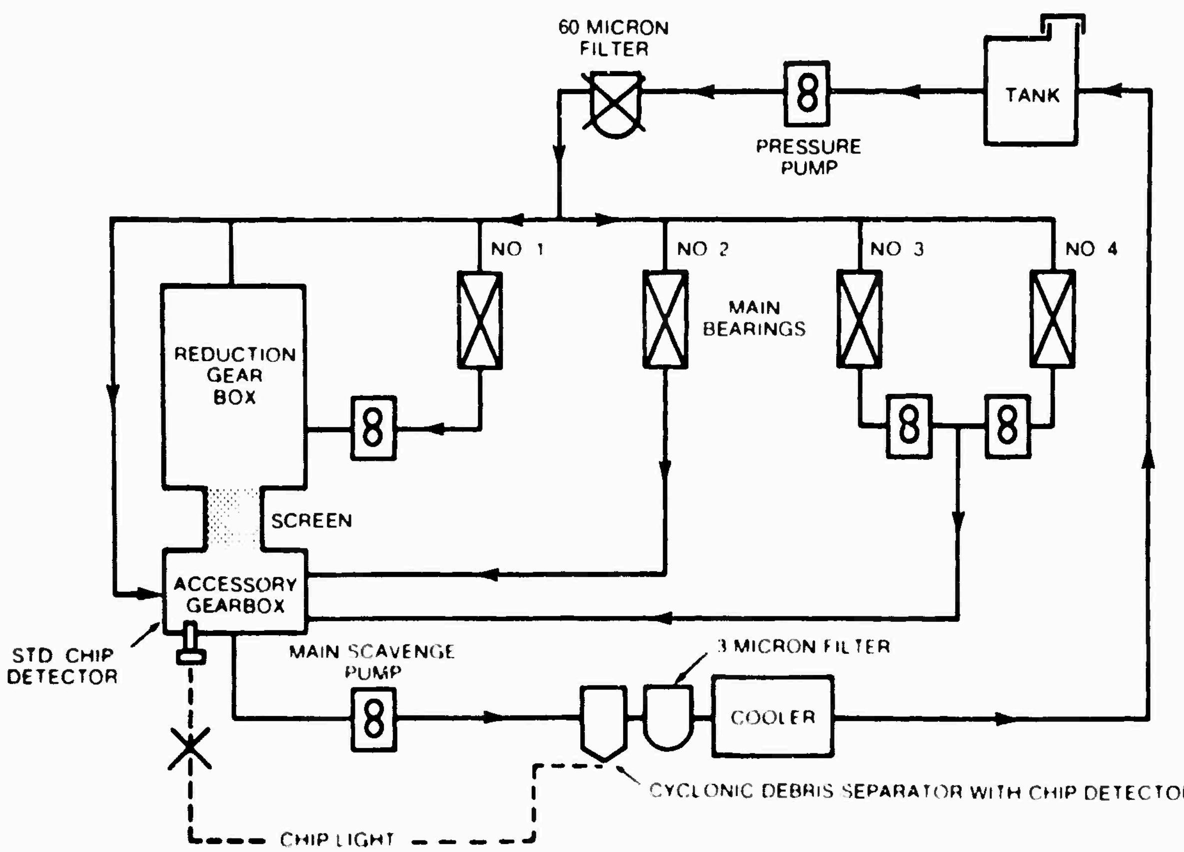

Figure 3. Engine lubrication system.

Gearboxes. Standard chip detectors were used in the 42- and 90-degree gearboxes.

Filters

The standard filter consists of a stack of cleanable wafers with a nominal rating of 60 microns. In addition, the US Army has been using an external 25-micron filter as standard equipment.

OIL DEBRIS DETECTION SYSTEM

The ODDS includes full-flow chip detectors, 3-micron filters, and burn-off detectors. It requires no scheduled activity on the part of maintenance or operator personnel; it is passive until a symptom of impending component failure is manifested, at which time a chip light is illuminated. Due to its operating principle of fuzz discrimination, about 50 percent of the chip-light-caused precautionary landings/mission aborts can be eliminated.

Chip Detectors

The principle of full-flow chip detection is shown in Figure 4; characteristic of this feature is that all of the oil is routed through the debris sensor. Although the concept is shown here as a mesh filter acting as an inlet screen on the suction side of the scavenge pump, for this evaluation the chip detector was located in the oil flow line on the pressure side of the scavenge pump (Figure 2). The failure detection reliability of full-flow chip detectors is very high and has been demonstrated through in-service experience and laboratory tests.

Transmission Chip Detector. The full-flow chip detector is designed to be a direct replacement for the wafer filter. The unit has two magnetic chip gaps on its circumference (Figure 5). On the left of the figure (shown upside down) is a removable screen which protects the downstream oil jet. The screen also has a cup-shaped inspection tray for nonmagnetic debris. This was added since regular inspection of the standard wafer filter sometimes identifies failures of nonferrous components.

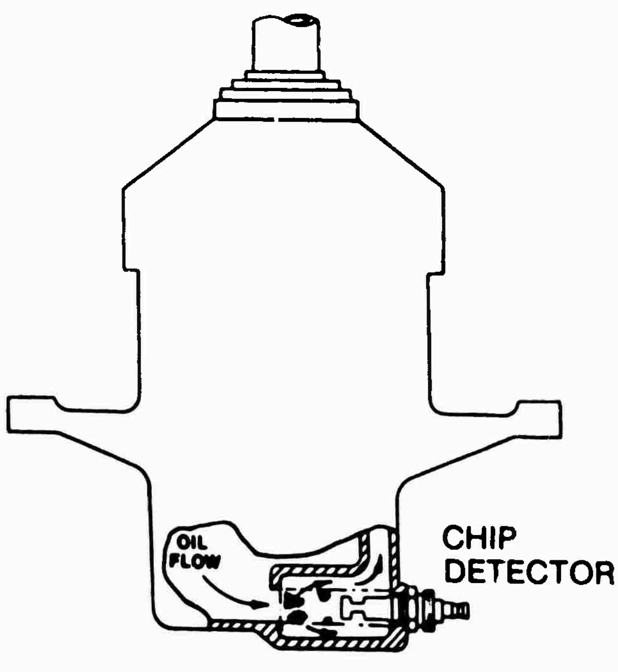

Figure 4. Full-flow chip detector.

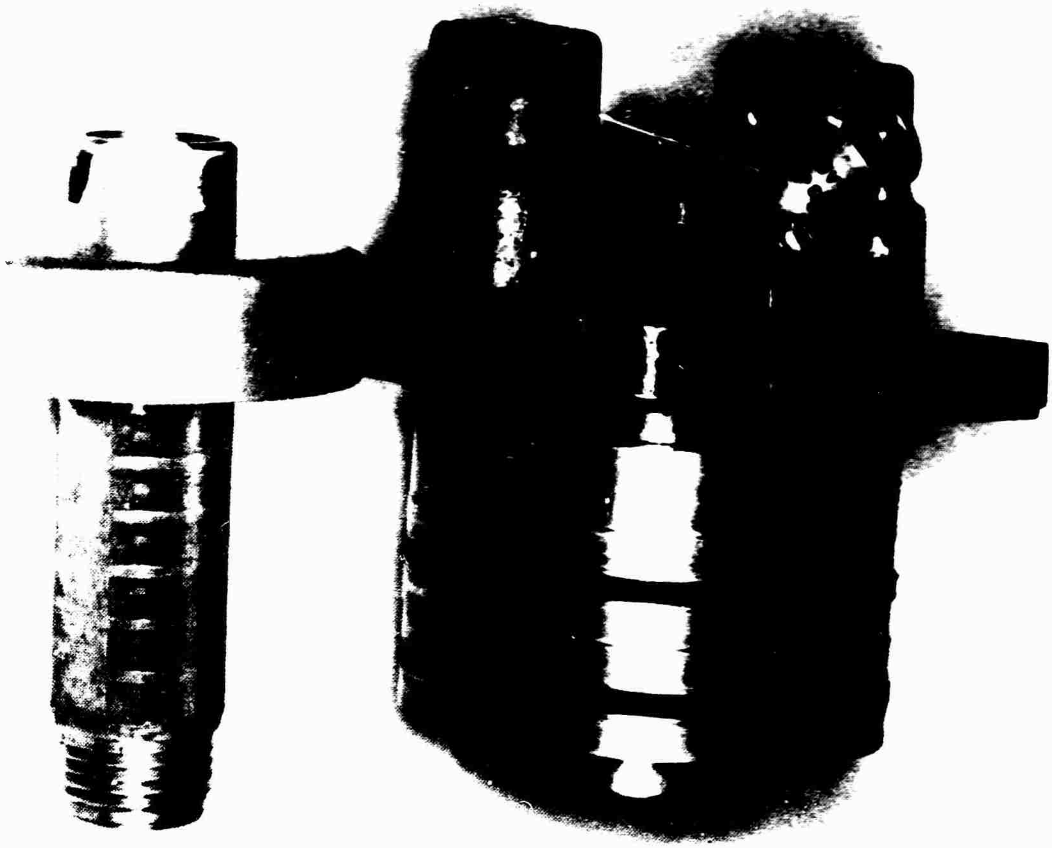

Figure 5. Transmission full-flow chip detector.

Engine Chip Detector. An external, high efficiency cyclonic full-flow debris separator/chip detector was developed (Figure 6) and added to the standard lubrication system along with the ultrafine filter. The engine installation in Figure 7 shows the cyclonic debris separator/chip detector attached to the ultrafine engine lube filter (the fuel filter is located underneath in a horizontal position).

Gearboxes. The standard chip detectors in the 42- and 90-degree gearboxes were replaced with units which have improved connectors and chip gaps optimized for burn-off operation.

Filters

Disposable ultrafine filter elements with a beta 3 of 200 were incorporated on the engines and transmissions of the test fleet. This rating means that these elements remove at least 199 out of 200 (or 99.5 percent) of all particles larger than 3 microns.

Figure 6. Engine cyclonic debris separator/chip detector.

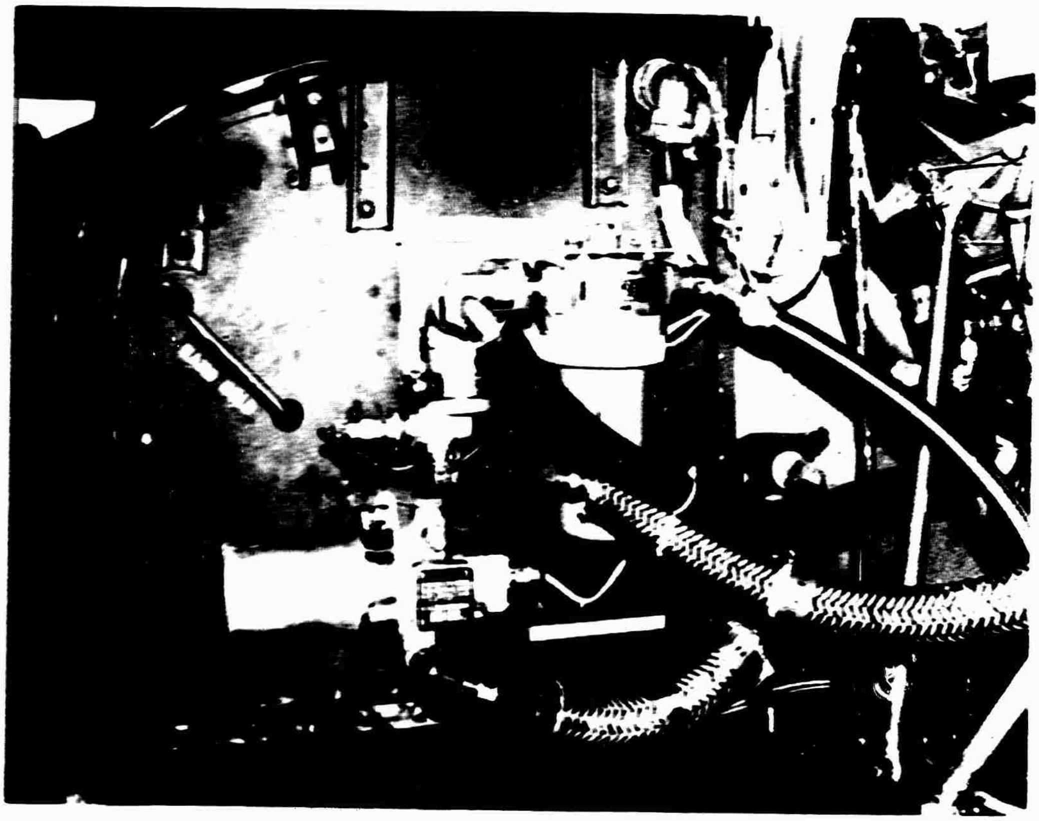

Figure 7. Engine filter and chip detector installation.

CONCEPT PRINCIPLES

FLOW-THRU DETECTORS/DEBRIS DISCRIMINATION

It is recognized that as failures progress, debris is generated in increasing quantity and size, generally in the manner shown in Figure 8. This relationship is fundamental in the diagnosis of failure progression — as the failure progresses, more and larger chips are generated and chip lights become more frequent.

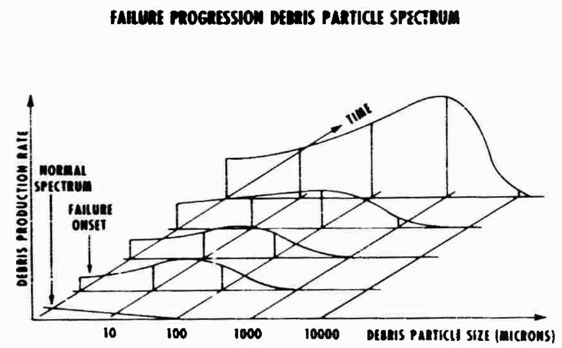

Figure 8. Failure progression debris particle spectrum.

In order for a detection system to reliably detect and identify failure debris as failures progress and to be useful as a monitoring tool, three basic parameters must be addressed: (1) the detection system must capture particles of a size that indicates a real impending failure; (2) it must have a high capture efficiency for these particles; and (3) the quantity and frequency of particles being generated must be known. One of the major features of the ODDS installed in the UH-1 test aircraft which addresses the above three parameters is referred to as "flow-thru." This means that all of the oil flow passes through the detector and therefore almost all ferrous debris will be captured and will provide an early warning of a potential problem with the oil-wetted components. (Due to the high capture efficiency resulting from the flow-thru feature, this system is the most effective detection system in operation today.)

Although a high capture efficiency is necessary for accurate, reliable diagnosis, that capability has the potential of producing operational problems in the form of chip light indications resulting from the capture of meaningless debris in the lube system. There are numerous sources of such benign debris. Often, spurious debris will result from maintenance actions involving the lube system, including the replacement of a component with one which has been newly overhauled. Residual overhaul debris is not infrequent and may be detected at any time in the component's life as it is dislodged.

Each engine and transmission will produce particles of wear and other debris which are not considered to be of concern and will develop different signatures with regard to debris classified as normal wear versus debris indicating true failure progression. In the case of the T-53 engine, the torque cylinder produces very fine wire- or hair-like debris on the detector (Figure 9). This debris can occur at any time during the life of this engine and does not indicate engine problems. Other systems, especially transmissions, have drastically different debris-generating characteristics. A larger, higher power transmission would generate more debris than a UH-1 transmission due to the component size. However, sensitivity of the detector would be the same as that for the smaller size transmission, since the sizes of the particles which must be detected for failure progression analysis are the same. Therefore, the larger system design must be tuned to capture the same size particles, but would allow for

Figure 9. Torque cylinder debris.

larger accumulation prior to illumination of the chip light. Techniques and/or procedures are required which will reduce/eliminate chip light indications that result in mission aborts or precautionary landings, but at the same time will provide a reliable and timely indication of impending failure.

It is apparent that identification of debris being generated by an incipient failure and the differentiation between that debris and unimportant debris must be accomplished in order to develop a meaningful and reliable failure-indicating system.

BURN-OFF CHIP DETECTOR

The operational principle of the fuzz burn-off chip detector involves the automatic discharge of a capacitor network after debris particles have bridged the gap of the two magnetic electrodes of the detector. A rapidly decaying pulse of energy controlled by capacitor size and operating voltage (28 volts) is applied to the debris bridging the gap. While current may reach 5 to 20 amps, the duration of the pulse is only a few millionths of a second. A single debris particle with a cross-sectional diameter of about 0.004 inch or larger easily passes this current and remains unaffected. By comparison, the kind of debris which frequently causes nuisance indications has much smaller cross sections, and often the particles are not visible with the unaided eye. A bridge across the chip gap consisting of such particles is melted through at the point of highest resistance by the discharge current. As a result, the chip light does not come on and unnecessary precautionary landings and maintenance actions are avoided.

CHIP LIGHT INDICATIONS

The contributors to chip light indications on the standard UH-1 fleet include the following: (1) fuzz accumulation on detector (33 percent); (2) normal benign wear debris accumulation

on detector (34 percent); (3) faulty wiring (21 percent); and (4) significant debris resulting in the component being removed (12 percent). Installation of the flow-thru detector with burn-off capability will totally eliminate the indications caused by items (1) and (3) and will reduce those caused by item (2).

FINE FILTRATION

The major benefit of the fine (3-micron) filtration system is increased component life as a result of a reduction in wear particles being circulated in the lubrication system. Past efforts have shown that bearings operating under various levels of filtration in a contaminated lubricant exhibited wear levels related to the filtration level. The bearings running in 3-micron-filtered lubricant were in "like new" condition after many hundreds of hours of operation at various loads and speeds as opposed to the bearings operating with coarser filters which were in a degraded condition. Studies by NASA and the US Naval Air Propulsion Center have corroborated these findings. Data from current flight test evaluations of 3-micron (absolute) filter-equipped T-53 engines and transmissions on UH-1 aircraft have shown that the bearings and gears were in "like new" condition and very clean after many hours of operation. In addition, no secondary damage was found on the engine bearings after one of the main shaft bearings had failed. The lack of secondary damage implies that fine filtration could result in a lower rejection rate of gears and bearings at overhaul.

PROGRAM DESCRIPTION

Using the UH-1 aircraft as a test bed, a diagnostic oil monitoring system was designed, incorporating high-efficiency, 3-micron filters and full-flow burn-off chip detectors in the engine and transmission, and with burn-off detectors in the 42- and 90-degree gearboxes. The test program was structured to establish the feasibility and utility of the improved oil debris detection system (ODDS) for use in Army helicopter engines, transmissions, and gearboxes. The ODDS was designed to reliably detect failures, to reduce the high rate of false and nuisance chip indications, and to reduce no-fault removals of oil-wetted components while improving component life and extending oil change intervals. It was expected that the effectiveness of the chip detector, coupled with the cleaning capability of the 3-micron filters, would substantially reduce the precautionary landings/mission aborts as well as relieve the maintenance and operational personnel of the heavy maintenance burden placed on them by the current AOAP process.

CHIP DETECTORS

On the UH-1, the major cause of false chip light indications from the conventional chip detectors is insignificant wear debris (67 percent), followed by electrical problems (21 percent) resulting from the detector's stud-type electrical terminals whose lug/wire interconnections are subject to fatigue and breakage.

In view of the preceding circumstances, the following features were incorporated in the debris-monitoring system of the test fleet:

- full-flow chip detectors for engine and transmission
- fuzz discrimination through "burn-off" for the engine, transmission, and 42-degree and 90-degree gearboxes
- improved connectors for all chip detectors

The location of the chip detectors in the test fleet transmission and engine systems provides full flow of the oil to pass by the detector (see Figures 2 and 3). Test data has shown that the full flow-thru chip detectors have a very high capture efficiency, and consequently a high number of indications may occur due to normal benign wear debris as well as debris being generated from impending failures.

FILTERS

The fine (3-micron) filtration system was incorporated in the engine and transmission lubrication systems due to its documented benefits. It is extremely beneficial in producing a "long-life" environment for gears and bearings. Components subjected to 3-micron filtration for many operating hours have proven to be far less distressed than similar components in standard filtered systems. Of particular interest is the great beneficial effect of 3-micron filtration on the the wear rate of seals – the test fleet experienced a significantly reduced seal removal rate.

CHIP LIGHT CONSOLE

For safety-of-flight reasons, it was a requirement of this program that the standard chip light system of the aircraft remain fully operational. The new chip indication system was therefore added to the cockpit console and was completely self-contained (Figure 10). It included chip lights for the engine, transmission, and 42- and 90-degree gearboxes. At the start of the

program the burn-off system was configured with pilot initiation of the burn-off pulse. Counters were included for counting the activations. Since the program showed that the system had very high failure detection effectiveness, the chip light console was reconfigured to a self-initiating mode in order to reduce student pilot workload, and the logging in of counter status was discontinued since the information obtained was not significant.

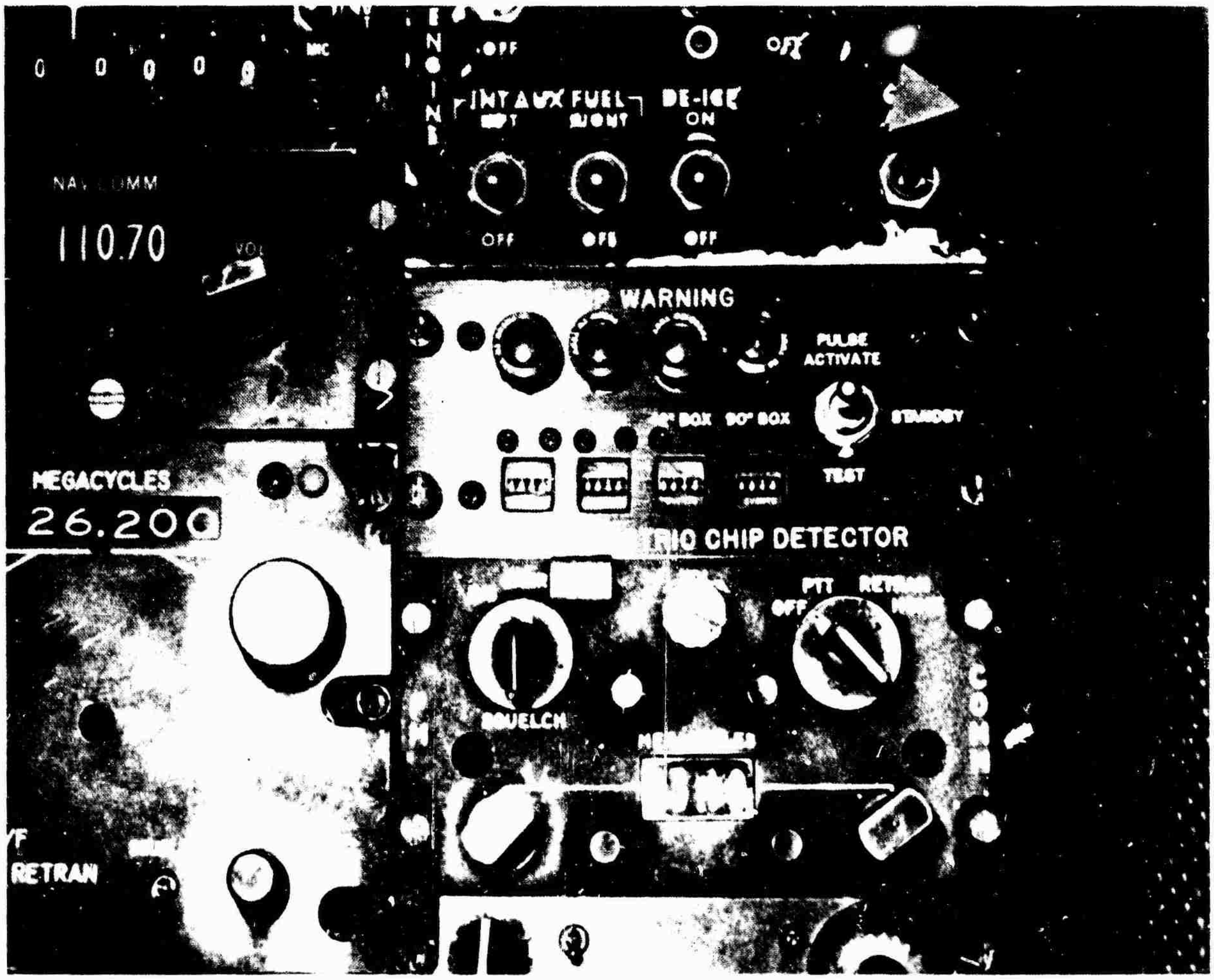

Figure 10. Chip light console.

TEST PROCEDURES

For the flight test evaluation on the UH-1 helicopters at USAADTA, 38 aircraft were equipped with the ODDS (incorporating ultrafine oil filters) and 12 unmodified aircraft were used as a control fleet for monitoring the oil condition. Over 80,000 flight test hours were accomplished. The tests and procedures are discussed below.

CHIP LIGHTS

Normal pilot procedures as described in the UH-1 operator's manual (TM55-1520-210-10) were followed upon illumination of the chip light. The event was also logged in the maintenance and test records.

DEBRIS ANALYSIS

Debris analysis was the diagnostic technique used for UH-1 engines, transmissions, and gearboxes. This technique is particularly important considering the ineffectiveness of spectrometric oil analysis techniques due to the filter's removal of debris that the spectrometer is normally capable of detecting. Since the chip detector captures magnetic debris before it can be removed by the filter, its diagnostic ability is not affected by the level of filtration.

In addition, the component evaluation methodology employed made use of all existing onboard diagnostic- and crew-reported discrepancies, i.e., magnetic plugs, unusual vibrations, overtemperature, overspeed, overtorque, oil pressure, and unusual noise. At the occurrence of a chip light indication, an oil sample was taken and submitted for AOAP examination. Diagnostic evaluations were conducted as follows.

Chip Detector Debris

On experiencing a chip light, the debris was evaluated by field maintenance personnel who initiated a chip detector incident report. The detector with the debris still in place was then submitted to the AOAP laboratory for documentation. After the debris was photographed, it was carefully removed from the chip detector, placed in freon, and filtered through a 0.45-micron membrane. The filter membrane and debris were placed between glass microscope slides for examination. This examination noted debris quantity, morphology, and type of material.

Oil Sample

When a chip light occurred, oil samples were taken and analyzed spectrometrically; the samples were filtered through a 0.45-micron membrane and evaluated microscopically with respect to morphology and type of material. This technique was used for detecting bronze bearing retainer cage failures and other nonmagnetic materials. When significant metallic debris was found on the membrane filter, an inspection of the aircraft screens and filters was requested.

Aircraft Screen and Filter Debris

When chip detectors or filter oil samples contained significant metallic debris, the debris was removed from the aircraft screens and filters and inspected. In the case of the engines, the inspection also included the debris removed from the chip detector swirl chamber. This debris was also evaluated with respect to morphology and type of material.

DOCUMENTATION

Following the occurrence of a chip light, USAADTA (the designated test monitor) documented the occurrence by aircraft tail number and component which had exhibited the indication. The documentation also included date, flight hours, type of debris, results of special oil samples taken, photos, and other pertinent data. These documents were sent to the Applied Technology Laboratory (ATL) on a biweekly basis for tracking purposes. After each component removal, a teardown inspection was performed and the results were thoroughly documented and correlated with chip light history. Components showing wear or damage were photographed. In this way, the historical loop consisting of chip indication, debris assessment, and teardown analysis was closed.

OIL CHANGE EXTENSION OIL SAMPLES

Oil samples were taken from both the test and the control aircraft at 50-hour intervals and forwarded to the Naval Air Propulsion Center, Trenton, New Jersey, for analysis to determine the effects of extended usage on the oil. The results of this effort are reported in Reference 1 and summarized in the Test Results section of this report.

COMPONENT INSPECTION

It was required throughout the flight test evaluation that components removed from the test aircraft because of metal contamination be inspected. Disassembly inspections were also required on some components removed for other causes, in the event chip lights had occurred prior to removal, in order to determine the origin of the particles causing the light to be illuminated. Some high-time components were also inspected to determine the effect of extended oil change intervals despite the fact that they had no chip light history. These inspections were performed by USAADTA personnel, and disassembly inspection reports (DIRs) were generated and are on file at ATL. The DIRs are discussed in the Test Results section.

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[1] Evaluation of Lubrication Oil Performance and Establishment of Oil Drain Intervals for UH-1 Aircraft, Report NAPC-PE-86, US Naval Propulsion Center, Trenton, New Jersey, September 1983.

PRELIMINARY DESIGN IMPROVEMENTS

SYSTEM DEVELOPMENT

Early in the flight test evaluation of the system, several design deficiencies were uncovered which required minor redesign or procedural changes for resolution. Four specific problems were identified and solved:

Chip Detector Sensitivity

A proper detector sensitivity had to be established. As the program developed, it was determined that detector sensitivity had to be reduced; this was accomplished by changing the gap of the detectors. The gap of the original engine detector was 0.055 inch; the gap was increased to 0.140 inch, which has been shown to be satisfactory. The original transmission detector had three chip gaps of 0.060 inch each; these were modified to two gaps measuring 0.090 inch each.

Trapped Particles in Engine Debris Separator

The original cyclonic debris separator contained a small cavity just below the burn-off chip detector. This cavity allowed debris to accumulate which sporadically (during engine startup and shutdown) came in contact with the indicator and caused a chip light. The cavity was filled and the problem eliminated.

Reingestion of Filtered Debris

Chip light illuminations were being caused by an inadequate design of the filter housing bypass system which allowed debris to be reintroduced into the engine and transmission. This required substantial modification of the filter assembly; therefore, a separate study was performed to evaluate its characteristics. This evaluation showed that the filter housings allowed the cold-start bypass flow to pick up debris from the filter bowl and sweep it back into the system (see Figure 11). New filter housings with improved bypass design were procured and installed on the test fleet.

Burn-Off Actuation

The cockpit display had a manual switching feature that required the pilot to initiate the burn-off pulse. The system was modified to automatically initiate the burn-off feature.

FREQUENCY OF CHIP LIGHTS

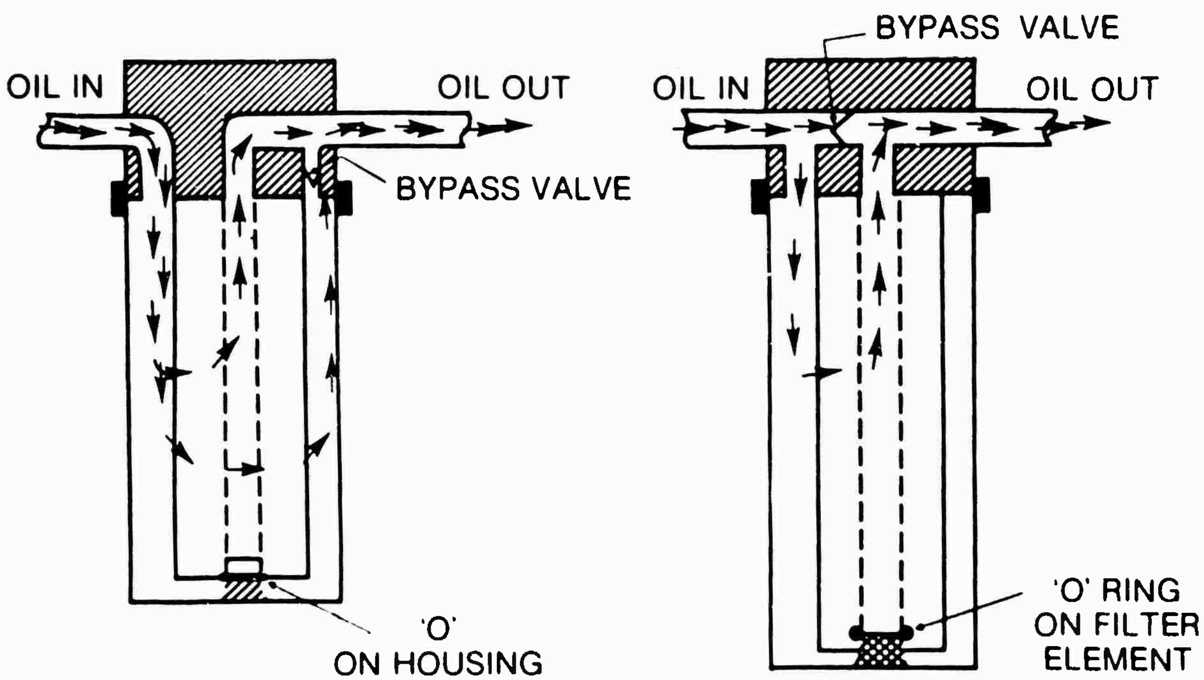
An evaluation of chip light occurrences indicated that, subsequent to maintenance actions performed on any part of the lubrication system and/or replacement of a component, chip light illuminations can be expected during the first 50 to 60 hours of operation. This process allows the system to clean itself of debris that was induced during maintenance action. A significant number of nuisance chip light indications can be eliminated by improving maintenance and incorporating 3-micron filters in the depot-level test stands during green run and/or acceptance testing of the components at the overhaul or manufacturing facility.

An additional contributor to the frequency of chip light indications is that on occasion a particular engine may become a debris generator. During this program, there were several engines which fell into this category. One is reported in Disasembly Inspection Report (DIR) No. 24. The engine had 2528 hours since overhaul (TSO) when it was installed in the test aircraft, and

it was removed from the test aircraft at 2726 TSO for foreign object damage (FOD) – actual time in the test aircraft was 198 hours. This particular engine produced nine chip lights, with the first occurring 52 hours after engine installation and the last eight occurring in the 146 hours prior to removal (18 hours mean time between chip lights (MTBCL)). Inspection of the engine after each of the chip light indications revealed minor to moderate metal particles, none of which would have warranted removal of the engine. Disassembly inspection of the engine revealed progressive deterioration of three components. The reduction gearing was found to be slightly pitted along the pitch line, which was barely visible to the naked eye. In addition, the torque cylinder was unevenly scored to a depth of less than 0.005 inch, and the No. 21 bearing exhibited edge pocket wear, and although barely visible, it was uniform in all roller pockets. None of these conditions was significant from a failure standpoint, although together they produced a low MTBCL. Had this engine not been removed for FOD, at some time the condition would have accelerated and produced a change in the size, shape, and quantity of debris, and the engine would have been removed because of metal contamination.

A statistical evaluation based on the initial 22,500 flight test hours showed the engine MTBCL to be 207 hours and the transmission 622 hours, with a large number of the chip lights resulting from insignificant debris and debris regurgitated from the filter. As previously discussed, these findings caused design changes to be incorporated into the detection system. Even though the earlier system produced excessive chip light indications, the data gathered provided a detailed evaluation of the effectiveness of the overall monitoring system.

Following correction of design deficiencies, the frequency of chip light illuminations was decreased significantly with no loss in diagnostic effectiveness. The chip light occurrence frequency for the ODDS is 0.004 per hour (250-hour MTBCL), which is approximately one-half the standard UH-1 rate (130-hour MTBCL); see Table 1.



a. Standard UH-1 filter.

b. Modified UH-1 filter.

Figure 11. Filter improvement.

TABLE 1. UH-1 CHIP LIGHT FREQUENCY

	Standard aircraft chip lights/hr	ODDS-equipped aircraft chip lights/hr
T-53 engine	0.00125	0.00333
42-deg/90-deg gearboxes	0.00500	0.00004
Main transmissions	0.00133	0.00058
Totals	0.00758	0.00395

48 percent reduction in chip lights with ODDS.

TEST RESULTS

Study of debris generated during this program, in conjunction with good disassembly inspection reports, provided a much clearer understanding of UH-1 engine and transmission wear/failure mechanisms. As a result, debris could be grouped into abnormal (failure) and benign categories. Particles resulting from progressing failures became easily distinguishable from benign debris, i.e., debris generated by the engine torque meter assembly or induced by maintenance. In cases of benign debris indications, maintenance action was not required.

The debris discrimination system tested on the UH-1 helicopter has demonstrated high accuracy and reliability in detecting incipient failures of the oil-wetted components well in advance of catastrophic failures. Table 2 lists the incipient failures which were discovered and recorded in teardown inspection reports. The failed components included the transmission mast bearing, input quill bearing, and gears, as well as the engine shaft bearings and accessory drive bearings. In all cases, the full flow-thru chip detectors provided early and repeated warnings. The important factor is that the chip lights experienced with the flow-thru detector were significant and were true indications that metal particles were present. AOAP samples were taken on a regular basis; however, none of the impending failures could be detected by AOAP since the 3-micron filters remove particles normally detectable with AOAP.

ENGINES AND TRANSMISSIONS

The flow-thru chip detector indicating system has consistently shown that multiple chip lights occur as an incipient failure progresses. The program was structured so that removed engines and transmissions were disassembled and inspected if they had previous chip light indications (regardless of the reason for component removal) in order to determine the origin of the particles causing the indications. DIRs were prepared for each of the teardown inspections performed; these reports are on file at ATL.

Appendix A presents 13 of the 41 DIRs available on components removed during the program (see Table 2 for DIR Summary). Selected component conditions following teardown inspections and a progression of chip lights as they occurred prior to component removal are also presented in Appendix A. Although all of the inspection findings are not discussed herein, typical examples are given.

The flow-thru system has detected the very early stages of gear scoring, bearings and seals rotating in their housings, surface fatigue of bearings, and wear of bearing cage pockets; these types of failures are not normally detected with the standard detection methods until the failure is in an advanced stage. In other words, the flow-thru chip detector system produces timely, repeated indications which relate to failure progression, whereas the standard methods produce none, one, or sporadic indications.

In several engines, it was found that the No. 21 engine bearing cage had failed. These engines were removed for inspection due to multiple chip light indications. Although the burn-off detector plugs did not reveal massive quantities of metal, special oil samples taken from the filter were microscopically examined and found to contain bronze particles; therefore, the engines were removed for metal contamination and inspected. Microscopic examination of oil samples was an established procedure when uncertainty existed with regard to quantity of particles on the detector. An example of a microscopic debris slide is shown in Figure 12.

Forty-one components (31 engines and 10 transmissions) were removed from the aircraft fleet and inspected. Of this group, 21 (15 engines and 6 transmissions) were removed as a result of multiple chip detector indications with the diagnosis that a failure was in process. The teardown inspection performed upon removal confirmed that diagnosis in all cases.

TABLE 2. DISASSEMBLY INSPECTION REPORT (DIR) SUMMARY

DIR No.	Reason for removal	Component condition	Remarks
		Engines	
1*	AOAP	Bearing rotating in housing	AOAP correct
2	Chip detector (CD) indications	Bearing rotating in housing	AOAP std det miss CD hit
3*	Maint. check	No. 4 bearing failed	AOAP and std det miss
5*	Standard detector indications	Bearing rotating in housing	AOAP miss
7	High vibration	Torque ring scored	Previous chip light debris eval
8	Oil leak	Seal failed	Previous chip light debris eval
9	CD indications	Bearing rotating in housing	CD hit
10	High EGT	Clean engine	High time w/o oil chg
11*	Oil leak	Seals deteriorated	High time w/o oil chg
12	Oil consumption	Seals deteriorated	High time w/o oil chg; previous chip light debris eval
15	N_1 lockup	Broken comp. blade	Previous chip light debris eval
18	FOD	Normal wear	High time w/o oil chg; previous chip light debris eval
19	CD indications	No. 21 bearing failed	CD hit
20	CD indications	No. 21 bearing failed	CD hit
21	CD indications	No. 21 bearing failed	CD hit
22	FOD	Normal wear	High time w/o oil chg; previous chip light debris eval
23*	FOD	Normal wear	High time w/o oil chg
24	FOD	Gears scored and torque cylinder worn	Previous chip light debris eval
25	CD indications	No. 21 bearing failed	CD hit
26	FOD	No. 2 bearing spalled, gears scored	Previous chip light debris eval
28	Oil leak	Bearing gear	Previous chip light debris eval
29	Hard starting	Fuel control problem	High time w/o oil chg
30	CD indications	Retainer problem	CD hit
31	CD indications	Seal rotating in housing	CD hit
32	CD indications	No. 21 and No. 2 bearing cages failed	CD hit

*Unmodified control aircraft

TABLE 2. Continued

DIR No.	Reason for removal	Component condition	Remarks
		Engines - Continued	
34	CD indications	No. 3 bearing rotating in housing	CD hit
35	CD indications	Bearing turning in housing	CD hit
36	CD indications	No. 21 bearing failed	CD hit
37	CD indications	No. 1 bearing spalled	CD hit
40	CD indications	No. 21 bearing failed	CD hit
41	CD indications	No. 3 seal rotating in housing	CD hit
		Transmissions	
4	Metal on filter (copper)	Normal wear	Maintenance error removal
6	CD indications	Triplex bearing spalled	CD hit
13	CD indications	Mast bearing spalled	CD hit
14	Clicking after assembly	Tooth chipped	Maintenance error
16	CD indications	Bevel gears scored	CD hit
17	CD indications	Mast bearing spalled	CD hit
27	CD indications	Mast bearing spalled	CD hit
33	CD indications	Planet bearing spalled	CD hit
38	CD indications	Normal wear	Maintenance error removal
39	Bronze on screen	Normal wear	AOAP - maintenance error removal

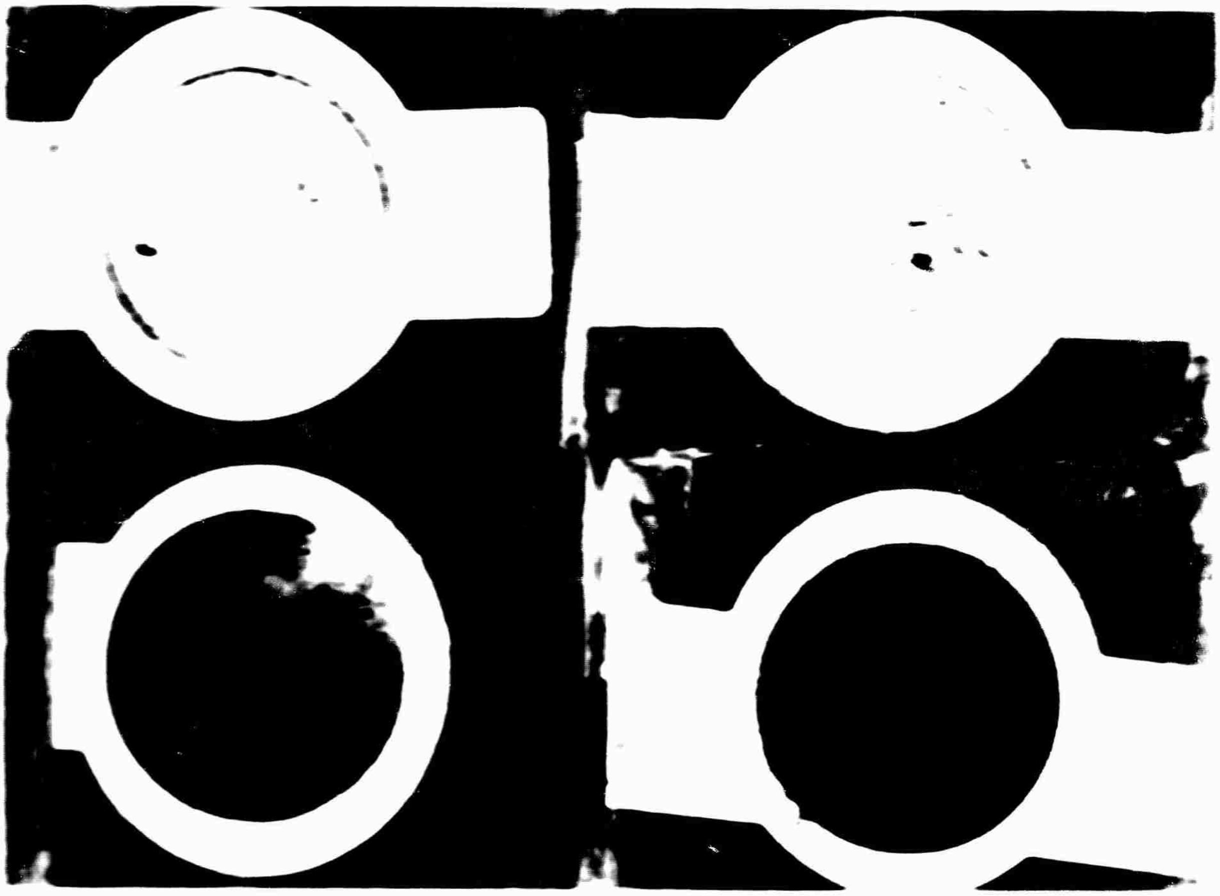


Figure 12. Membrane filter debris slides.

The other 20 components (16 engines and 4 transmissions) were removed for reasons other than metal contamination, e.g., FOD, oil consumption, and seal leakage. Generally, these high-time components were inspected in order to assess the effect of no oil changes with both filtration levels and to confirm that there were no failures in process.

Teardown inspection of high-time standard aircraft components showed no adverse effects of extended oil usage. The inspection of high-time components with 3-micron filtration also revealed no adverse effects. In fact, these components were judged to be in superior condition with no sludge and extremely light wear patterns. Seal damage in the 3-micron filtered components was generally much less than is experienced in the standard UH-1 fleet.

Inspection of the 31 components suspected of not having failures confirmed that condition in all cases. Thus, it is seen that not only is the [illegible] effective in detecting the presence of progressing failures but it is equally effective in not allowing the failures to go undetected. The accuracy in diagnosing the condition of the gears and bearings results from the diagnostic criteria and the basic operating characteristics of the [illegible], that is, it is sensitive to only that debris which is indicative of failure and it has an extremely high capture efficiency for that debris. Therefore, if chips of a meaningful size are generated, they will be caught by the [illegible] and the light will be illuminated. Conversely, if chips are not being generated, no failure is in process and no indication will be made.

GEARBOXES

No 42- or 90-degree gearboxes were removed for metal contamination during the 80,000-hour flight test. Only three chip lights were recorded during that period, which evidences the effectiveness of the fuzz burn-off feature. Using the data of Table 1, it can be seen that the standard fleet experiences a chip light in one of these gearboxes every 200 hours. For comparative purposes, standard fleet aircraft would therefore expect to have 400 gearbox chip lights in 80,000 hours of operation. It is reasonable to conclude that the difference in the number of chip lights between the two fleets (400-3 = 397) is caused by "normal fuzz" and by other standard system deficiencies. Numerous conclusions can be drawn about the adverse safety and economic impacts of such a large number of absolutely meaningless chip lights and the resultant precautionary landings.

OIL CHANGE INTERVAL INCREASE

The original goal of increasing the oil change interval for the UH-1 engine and transmission to 1000 hours was successfully exceeded. Oil change intervals were increased to 2000 hours. During the program, oil samples were taken from both the test and the control aircraft at 50-hour intervals and tested. Oil samples continued to be in good condition as additional hours were accumulated without an oil change. During the program, a total of 27 engines and 26 transmissions exceeded 1000 hours of operation without an oil change, and the highest-time engine and transmission reached 2343 and 2000 hours respectively. A detailed report on the results of the tests conducted on oil samples taken from the program aircraft is presented in Reference 1. The general conclusions presented in that report were as follows:

1. Under normal operating conditions, MIL-L-23699 lubricating oils will perform satisfactorily in the oil systems of the engines and transmissions of UH-1 helicopters for extended oil-drain periods of 2000 hours, while remaining in good chemical and physical condition. The foregoing applies to UH-1 lubricating systems equipped with either 3-micron or standard 25-micron filters.

2. The oil-wetted areas of the engines and transmissions equipped with lubricating systems employing 3-micron filters were much cleaner (i.e., free of debris) than those equipped with standard filters.

3. With the exception of the decreased wear of the oil seals located in the bearing cavities, no visual difference was noted in the wear of the oil wetted mechanical components of the engines or transmissions whether equipped with 3-micron or standard filters. Even though no improvement in life (extension of the average TSO when removed for cause) resulted from use of the 3-micron versus standard filter, it can be anticipated that the more efficient removal of metallic particles by the 3-micron filter will result in reduced wear, especially of seals.

4. The chemical and physical condition of the MIL-L-23699 lubricating oil contained within the engines and transmissions of UH-1 aircraft can deteriorate within several hundred hours under adverse mechanical conditions (i.e., failure of a gear, bearing, or oil seal) or by means of an inadvertent admittance of water into the lubricating system.

5. A failure or impending failure of an oil-wetted component, such as an oil seal, is often accompanied by an abrupt rise in the viscosity and acid number of the lubricating oil.

6. The results of the foaming tests performed on used MIL-L-23699 lubricating oils were not indicative of a change in foaming characteristics demonstrated by the use of the oil in actual service.

7. The use of a 3-micron filter in a lubricating system nullifies the use of current spectrometric analysis as a means of detecting impending failures.

8. No corrosion occurred to the oil-wetted parts of the engine or transmissions after having been in continued service for up to 2 years 8 months; neither did excess water condense and become captive in the lubricating system after such long periods of use. It should be noted that the aircraft were in constant use (extended storage of the aircraft would probably produce different results).

FILTER ELEMENT LIFE

It had generally been assumed that the life of ultrafine filters would be shorter than that of coarser filters, but the opposite proved to be the case. The oil systems required initial cleanup as the test fleet was switched over to ultrafine filters. The initial elements had to be replaced soon after installation (about 350 hours) since they became loaded with residual particles in the oil and in the lube systems. After the first replacement, the average filter life increased to 1000 hours as the systems became cleaner. The high-time filter reached 1400 hours. It appears that much less debris is being generated due to abrasive wear as a result of the high cleanliness level of the oil. This, in turn, reduces the rate of contamination of the filter.

COST ANALYSIS

An assessment of the projected cost savings for retrofitting the current UH-1 fleet with the ODDS is shown in Appendix B. This analysis has indicated that retrofitting the fleet would result in a 10-year return on investment of 5 and that the installation break-even point would be less than 2 years.

CONCLUSIONS

1. The ODDS is an on-line, real-time system which reliably and accurately detects impending failures of oil-wetted components well before their presence is of concern. It requires no scheduled activity on the part of operator or maintenance personnel and remains passive until symptoms of impending component failures are manifested. Further, as a result of its operating principle, it will prevent no-fault removals.

2. Due to its reliable and accurate early detection of incipient failures, the ODDS on the UH-1 main transmission will allow on-condition maintenance to replace the current time-based change interval.

3. Based on the results of the large number of test aircraft oil samples subjected to AOAP analysis, the use of the 3-micron filter renders the current AOAP useless.

4. Analysis of the oil taken from the test and control aircraft fleet has indicated that the oil change intervals of the main transmission, the T-53 engine, and the gearboxes in the UH-1 helicopters can be safely extended to 2000 hours. Further, it has been shown that filtration level does not control oil condition or change intervals. The current procedure of changing oil on a time basis can be terminated and oil changes can be made on the basis of oil condition.

5. Assembly and maintenance-induced debris contributes significantly to the number of false or nuisance chip light occurrences.

6. The system as tested, with chip lights in the cockpit, caused a 48-percent reduction in chip light indications and the resultant precautionary landings.

7. Failure progression of any component occurs over a considerably longer period of time (at least 100 hours) than any one particular flight. It has been found that no single chip light is of importance, since components produce many chip lights during the progression of a failure. Hence, the cockpit indicating light can be placed in the maintenance bay of the helicopter and included as a post-flight inspection item with no decrease in diagnostic effectiveness. In so doing, precautionary landings due to chip light indications would be eliminated and an increase in safety would result.

8. The wear rate of seals is significantly reduced with the use of 3-micron filters in the lubrication system.

9. Component inspection results indicate that secondary damage and sludge buildup is significantly reduced with the 3-micron filtration system installed, and it is expected that component life will be significantly increased.

10. Based on the analysis found in Appendix B, a significant cost avoidance can be realized when the system developed under this program is incorporated in the Army fleet.

11. Through incorporation of ODDS, coupled with the techniques and methodologies developed, realistic component removal decisions can be made at the unit level.

RECOMMENDATIONS

Based on the results and the conclusions drawn from this effort, it is recommended that:

1. A production version of the ODDS including the changes shown in Appendix C be incorporated in the current UH/AH-1 helicopter fleet.

2. The ODDS technology be incorporated in all existing Army aircraft and included at the inception of future aircraft systems and component developments.

3. With the incorporation of the ODDS, the UH/AH-1 main transmission maintenance be on-condition rather than time based.

4. Due to the ability of the chip detection system to reliably detect incipient failures, the cockpit indicating light be placed in the maintenance bay of the helicopter and included as a post-flight inspection item. This would totally eliminate precautionary landings due to chip light indications.

5. All engine and transmission development and acceptance test stands incorporate 3-micron filters to aid in the removal of miscellaneous debris prior to shipping to the field, in order to take full advantage of the benefits of the clean operating environment for the oil-wetted components.

6. The oil change interval for the current fleet (without ODDS) be eliminated, and oil changes be based on oil condition.

7. Upon incorporation of the ODDS, with the techniques and methodologies developed, AOAP sampling and analysis procedures be terminated and maintenance removal decisions be made at the unit level.

APPENDIX A
TEARDOWN INSPECTIONS AND ANALYSIS

DIRs were prepared on 41 components that were removed and inspected during this program: 10 main transmissions and 31 engines. This appendix presents some of the chip light indications which occurred prior to component removal and inspection. Failure progressions as detected by the flow-thru chip detectors, as well as other warnings which preceded component removal, are discussed. Figures A-1 through A-6 show the condition of various components whose debris had caused the chip light indications. It can be noted from the figures that catastrophic failures were avoided. Additionally, there were no oil-wetted components that had failed or were progressing toward a failure which were not detected by the flow-thru detector system. It can be stated that the detection system has a 100-percent probability of indicating all surface fatigue related impending failures of the oil-wetted components. Several of the DIRs are discussed in more detail on the following pages.

INSPECTIONS

1. DIR No. 6 - main transmission

   Reason for removal: metal on chip detector
   Inspection results: triplex bearing spalled
   Failure progression time: 102 hours
   Chip light illumination hours prior to removal:

   Standard - 102

   ODDS - 58, 23, 20, 11, 5, 0

2. DIR No. 13 - main transmission

   Reason for removal: metal on chip detector
   Inspection results: mast bearing spalled
   Failure progression time: 181 hours
   Chip light illumination hours prior to removal:

   ODDS - 181, 157, 154, 131, 112, 92, 0

3. DIR No. 16 - main transmission

   Reason for removal: metal contamination on chip detector
   Inspection results: bevel gear scored
   Failure progression time: 112 hours
   Chip light illumination hours prior to removal:

   Standard - 112, 76, 3

   ODDS - 0

4. DIR No. 17 - main transmission

Reason for removal: metal found in filter after chip light
Inspection results: mast bearing spalled
Failure progression time: 190 hours
Chip light illumination hours prior to removal:

ODDS - 190*, 0

*Burn-off detector not installed between 190 and 0

5. DIR No. 20 - T-53 engine

Reason for removal: metal contamination (bronze in oil sample)
Inspection results: No. 21 bearing cage failed
Failure progression time: 130 hours
Chip light illumination hours prior to removal:

Standard - 12*, 3, 0**

ODDS - 130, 13

*Burn-off detector not installed between 12 and 3.

**Two illuminations at 0.

6. DIR No. 21 - T-53 engine

Reason for removal: metal contamination on chip detector and in oil sample
Inspection results: No. 21 bearing cage failed
Failure progression time - 29 hours
Chip light illumination hours prior to removal:

ODDS - 192, 165, 29, 22, 6, 2, 0

7. DIR No. 24 - T-53 engine

Reason for removal: FOD
Inspection results: gears scored, torque cylinder and bearing cage worn
Failure progression time: 146 hours
Chip light illumination hours prior to removal:

ODDS - 146, 142, 112, 86, 65, 49, 34, 10

8. DIR No. 25 - T-53 engine

Reason for removal: metal contamination on chip detector and in oil sample
Inspection results: No. 21 bearing cage failed
Failure progression time: 122 hours
Chip light illumination hours prior to removal:

ODDS - 223, 122, 113, 100, 85, 83, 0

9. DIR No. 26 - T-53 engine

Reason for removal: FOD
Inspection results: No. 2 bearing race spalled, gear scored, and torque cylinder worn
Failure progression time: 107 hours
Chip light illumination hours prior to removal:

Standard - 496

ODDS - 107, 92, 10

10. DIR No. 27 - main transmission

Reason for removal: metal contamination on chip detector
Inspection results: mast bearing spalled and gear scored
Chip light illumination hours prior to removal:

ODDS - 79, 66, 56, 47, 27, 0

11. DIR No. 28 - T-53 engine

Reason for removal: excessive oil leak
Inspection results: No. 4 bearing worn due to overtemperature
Failure progression time: 49 hours
Chip light illumination hours prior to removal:

ODDS - 382, 357, 49, 10, 9

12. DIR No. 31 - T-53 engine (Figure A-7)

Reason for removal: excessive metal contamination
Inspection results: No. 3 carbon seal turning in housing
Failure progression time: 90 hours
Chip light illumination hours prior to removal:

ODDS - 90, 76, 22, 13, 1, 0

The engine documented in DIR No. 2 was removed for metal contamination on the burn-off detector; it had chip light indications on four occasions in 1.4 hours after the test system was installed. After the four occurrences, the cyclonic oil particle separator and 3-micron filter bowl were inspected and found to contain ferrous metal debris. The engine had been in operation for 900 hours prior to installation of the test system with no standard chip detector indications and normal AOAP analysis results. The 3-micron filter was removed and the burn-off chip detector disconnected for an additional 16.2 flight hours. At the end of this time, AOAP analysis still failed to confirm a problem and there had been no chip indications on the standard engine chip detector. The engine was then removed for disassembly inspection which revealed that the No. 2 bearing had been rotating in its housing.

In the case shown in DIR No. 20, the engine was removed from service due to several chip lights within a short period of time. At the last incident, the Oil Analysis Lab discovered bronze particles in a special oil sample taken from the filter using microscopic analysis. There had been seven engine chip detector lights beginning 130 hours prior to this removal. The first three lights were on the burn-off chip detector. The next four lights were with the

standard detector, the test detector having been removed for modification. Spectrometric oil analysis was normal throughout this time.

In the case shown in DIR No. 25, the engine was removed for the same reason as the engine shown in DIR No. 21; the inspection revealed identical failures. Although there had not been a series of chip lights in a short period of time, inspection of an oil sample taken from the filter bowl after the chip light indication revealed large quantities of bronze powder.

In the case shown in DIR No. 28, the engine was removed for an excessive oil leak. The first two chip lights, which occurred 382 and 357 hours prior to removal, were of no concern, since more than 300 hours of engine operation took place before the next light occurred at 49 hours prior to component removal. This was followed by two more lights before engine removal. Only the last three chip lights were indicating that an impending failure was progressing. The No. 4 bearing, which is a split inner race angular contact ball thrust bearing, showed signs of heavy frosting and wear high on the shoulder of the race and indicated higher than normal operating temperature. Upon checking the hardness of this bearing, it was found that due to the high temperature operation, race hardness had significantly decreased below minimum of R_c=58; hardness in the frosted area of the bearing race ranged from R_c=51.5 to R_c=56.5. Additionally, due to the geometry of the cyclonic debris separator with the chip detector located in a cavity at the lowest point, magnetic particles are not all that are captured. The chip light which occurred 49 hours prior to removal had particles of carbon trapped in the cavity of the detector, thereby indicating a potential problem associated with the engine shaft seals, which ultimately caused the engine to be removed. Since the carbon particles from the seal are extremely hard, they would have caused secondary damage (not evident in this engine) to other oil-wetted components had the 3-micron filter system not been installed on this engine.

Figure A-1. Inner bearing race from DIR No. 6.

Figure A-2. Bearing retainer from DIR No. 6.

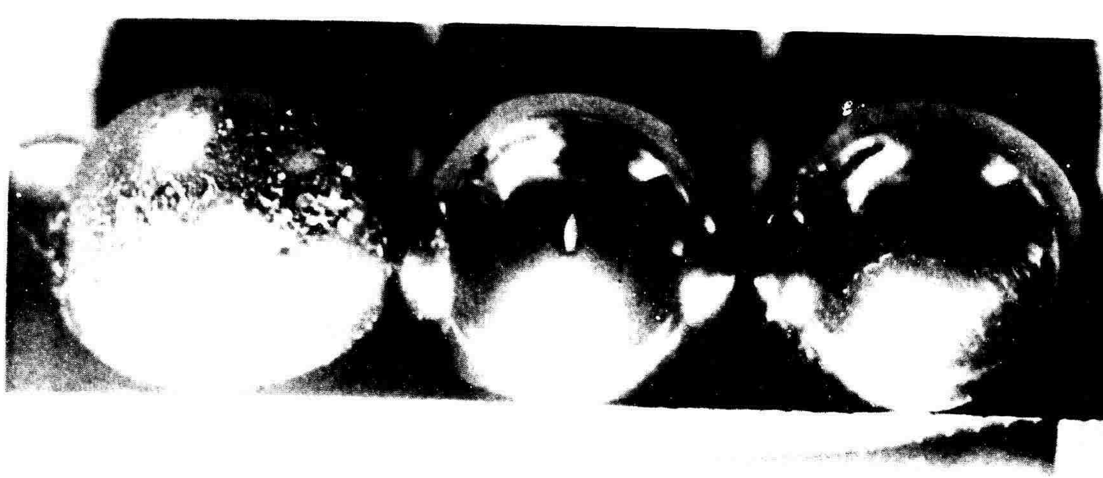


Figure A-3. Balls from bearing of DIR No. 6.

Figure A-4. Outer race mast bearing from DIR No. 13.

Figure A-5. Inner race mast bearing from DIR No. 13.

Figure A-6. Metal detected on mast bearing from DIR No. 13.

Figure A-7. No. 3 shaft seal from DIR No. 31.

APPENDIX B
OIL DEBRIS DETECTION SYSTEM COST SAVINGS SUMMARY

Cost savings and operational readiness (OR) improvements for the ODDS are presented in this appendix. The analysis is summarized below and discussed more extensively on the following pages.

Item	Cost Saved	Aircraft Hours Saved
Removal of TBO from transmission	$2,665,680	6,240
On-condition filter element replacement	82,152	2,034
Oil samples not required	2,439,880	27,111
Reduction in precautionary landings	2,294,160	27,336
System drain and flush	89,700	1,790
No-fault removals, engine and transmission	82,466	1,045
Reduction in spares cost	176,840	0
Totals	$7,830,878	65,556

Intangible benefits not included in savings analysis are yearly cost savings during wartime of $14 million, reduction in consumables and maintenance burden, and unscheduled maintenance. ODDS provides for increases in mission reliability, aircraft availability, and improved safety. The estimated cost to retrofit a 4000 aircraft fleet with the complete ODDS is $12,500,000. Based on constant 1983 dollars, the payback on such a system is 1.6 years after fleet installation.

The following cost savings and OR rate improvement analysis is based on the ODDS fleet of 4000 UH/AH-1 helicopters. The average flight hours per year for this fleet is assumed to be 800,000. Various assumptions have been made in the following analysis; all assumptions are believed to be conservative and are used where specific values are not known. Other statistical data are presented and the sources of these data are shown.

Aircraft hours used in the following analysis do not include the wartime role of these helicopters. Based on projected wartime usage, the cost savings and increased OR shown would more than double. Considering the peacetime scenario, the OR rate improvement is

$$\frac{65{,}556}{35{,}040{,}000} = 0.19\%$$

The increase in available flight hours per year is

$$\frac{65{,}556}{800{,}000} = 8.2\%$$

REMOVAL OF TBO FROM TRANSMISSION

MTBR will increase from the current 1250 hours[a] to 2000 hours[b]

Therefore $\frac{800{,}000}{2{,}000}$ = 400 transmission overhauls/year (new system)

$\frac{800{,}000}{1{,}250}$ = 640 transmission overhauls/year (old system)

This results in 240 less transmission overhauls/year x $9107[c] = a cost savings of $2,184,000

Field labor to remove and replace 240 transmissions = $30 per hour[d] x 60 maintenance man-hours (MMH)[b] x 240 = $432,000

Cost to ship 240 transmissions = 240 x $162[a] = $38,880

30 gal. of fuel for maintenance operations check (MOC)[a] x 240 = 7200 gal. @ $1.50 = $10,800

Total saved = $2,665,680

26 aircraft hours are required for all removals and replacements;[b] this includes a 30-min MOC

26 x 240 = 6240 aircraft hours

ON-CONDITION FILTER ELEMENT REPLACEMENT

Standard system $\frac{800{,}000}{150 \text{ hr}}$ = 5400 replacements/year

Replacement cost for standard filter = 5400 x $12 each = $64,800

Two 3-micron filters (one on transmission, one on engine) $\frac{800{,}000}{1{,}200}$ = 1332 x $45 each = $59,940

5400 -1332 = 4068 less filter changes/year with ODDS

Labor to change filter = 4068 x 1/2 hour[a] x $30 = $61,020

1/2 hour x 4068 = 2034 hours the aircraft is not available

Topping off with oil after change = 4068 x 1 qt x $4 = $16,272

Total saved = $82,152

(a) Data is assumed
(b) Sample Data Collection
(c) Corpus Christi Army Depot
(d) US Army Aviation Systems Command

OIL SAMPLES NOT REQUIRED

Current engine: $\dfrac{800{,}000}{12}$ = 66,666 samples

Current transmission: $\dfrac{800{,}000}{25}$ = 32,000 samples

Current 90-deg gearbox: $\dfrac{800{,}000}{25}$ = 32,000 samples

Current 42-deg gearbox: $\dfrac{800{,}000}{25}$ = 32,000 samples

Total samples standard system = 162,666

162,666 samples at \$5[e] = \$813,220 total labor cost

20 minutes/sample for field labor[a] = 54,222 hours x \$30 = \$1,626,660

Total saved = \$2,439,880

REDUCTION IN PRECAUTIONARY LANDINGS

3.63 less chip lights/1000 flight hours[d]

49% of landings are off-site and require 14 hours to recover[f]

51% of landings are on-site and require 5 hours to recover[f]

49% x 3.63 = 1.7787/1000 less recoveries off-site

51% x 3.63 = 1.8513/1000 less recoveries on-site

1.7787 x 800 x 14 hours = 19,921 hours aircraft not available

1.8513 x 800 x 5 hours = 7,405 hours aircraft not available

Total hours aircraft not available = 27,326

Cost = 800 x 1.7787 x \$1300[a] per recovery = \$1,849,848

800 x 1.8513 x 5 hours x 2 MMH x \$30 = \$444,312

Total saved = \$2,294,160

(e) USA DARCOM Materiel Readiness Support Activity
(f) Aviation Safety Center

SYSTEM FLUSH AND DRAIN

Special Oil Samples = 1/1000 hours of operation[a]

2 aircraft hours required/operation = 2 x 800 = 1600 aircraft hours

Cost = 2 MMH x $30 x 800 = $48,000

Fuel cost for MOC after flush and drain = 30 gal. x $1.50 x 800 = $36,000

Components Removed for Contamination

59 engines removed for oil contamination/year[c]

36 transmissions removed for oil contamination/year[a]

Total = 95 components removed for contamination

ODDS does not require system flush after component replacement

95 components replaced @ 2 aircraft hours for flushing = 190 hours

190 hours x $30 = $5,700

Total saved = $48,000 + $36,000 + $5,700 = $89,700

NO-FAULT REMOVALS, ENGINE AND TRANSMISSION

9 engines/year,[c] 10 transmissions/year[a]

50 MMH required to remove and replace engine

60 MMH required to remove and replace transmission

50 x 9 + 60 x 10 = 1050 MMH/year (MMH includes two men)
525 aircraft hours total

Cost = Engine, 50 MMH x $30 x 9 = $13,500

Transmission, 60 MMH x $30 x 10 = $18,000

Shipping engine: $194 x 9 = $1,746

Shipping transmission: $162 x 10 = $1,620

Depot labor (engine): 120 MMH[a] x 30 x 9 = $32,400

Depot parts (engine): $200[a] x 9 = $1,800

Depot labor (transmission): 40MMH[a] x $30 x 10 = $12,000

Depot parts (transmission): $140 x 10 = $1,400

Total saved = $82,466

REDUCTION IN SPARES COST (10%)

$$\text{Engine overhauls/year} = \frac{800{,}000}{950} = 842$$

$$\text{Transmission overhauls/year} = \frac{800{,}000}{1{,}250} = 640$$

Engine spares cost = $200[a] x 842 = $168,400 x 10% = $16,840

Transmission spares cost = $2,500[a] x 640 = 1,600,000 x 10% = $160,000

Total saved = $176,840

APPENDIX C
PRODUCTION CONFIGURATION FOR FUTURE DEVELOPMENT

Cost-effective production methods will be used to fabricate hardware for fleet implementation of the ODDS. Existing aircraft wiring and annunciation panels will be used as much as practicable. Additions or deletions to the design will be made to enhance reliability and provide maintainability features not incorporated in the prototype system. These features include the following:

1. The filter assembly for the engine and main transmission will incorporate a V-band clamp between the filter head and bowl which will replace the prototype screw-on bowl. A production casting will replace the prototype machined block filter head and a drain valve will be added to the filter bowl. A wraparound screen will be provided around the filter element.

2. The engine cyclonic debris separator will be fabricated to a production lightweight design to replace the prototype machined block and will have an integral chip detector with a 0.140-inch chip gap and a drain valve for oil sample removal. Consideration will be given to the incorporation of a deaeration device in the debris separator.

3. The main transmission chip detector will have the universal finger screen design incorporating the conical cup and thick wall design (see Figure C-1).

4. The 42- and 90-degree gearbox chip detectors will be provided with a production lightweight design to eliminate the attachment wear discovered during prototype tests.

Figure C-1. Transmission detector screen.

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